STAFF REPORT

IEW OF THE PROCEDURES FOR THE COLORADO RIO GRAN
ESCS - SCS LINEAR PROGRAMMING MODEL

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AN OVERVIEW OF THE PROCEDURES FOR THE COLORADO RIO GRANDE TYPE IV STUDY ESCS - SCS LINEAR PROGRAMMING MODEL

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AN OVERVIEW OF THE PROCEDURES FOR THE COLORADO RIO GRANDE TYPE IV STUDY ESCS - SCS LINEAR PROGRAMMING MODEL

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AN OVERVIEW OF THE PROCEDURES FOR THE COLORADO RIO GRANDE TYPE IV STUDY ESCS - SCS LINEAR PROGRAMMING MODEL. By Ronald R. Rhoade and T. Niles Glasgow, Natural Resource Economics Division; Economics, Statistics, and Cooperatives Service; and Soil Conservation Service, U.S. Department of Agriculture; Washington, D.C. 20250 MARCH 1980

ABSTRACT

ESCS and SCS jointly developed a crop, pasture and range linear programming model for the Rio Grande Type IV River Basin Study. A base year model representing years 1970-72 plus twelve projected models were run. Nine early action watershed projects were included in the 2000 NED run and 34 long-range watershed projects were included in the 2020 NED run. These were in addition to the without project runs for comparison and the EQ runs which encompassed only two watershed projects. The remaining runs were made to evaluate the economic cost of transferring center pivot irrigated field corners to wildlife habitat.

Key words: Colorado; Rio Grande Type IV; linear programming; center pivot; water resources; irrigation; land use; river basins.

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SUMMARY

The Economics, Statistics, and Cooperatives Service and the Soil Conservation Service jointly developed a profit maximizing (maximum returns to land and management) linear programming (LP) model for the Colorado Rio Grande Type IV River Basin Study.[1/] The model encompassed crop, pasture and range production on state and private lands. In addition to a base period LP run, twelve runs were developed for the various study plans in years 2000 and 2020. The base run was established from the 1970-72 crop acreage, yield and production inventory. Prices and costs, however, were standardized at 1974 prices and costs for the base years and 2000 and 2020 projected runs.

The study area is located in South Central Colorado. The area comprises about 2.4 million acres of state and private land of which about 610 thousand acres are irrigated. About 404 thousand acres of the irrigated acres are cropland.

The model developed was unique among river basin LP models in that actual watershed projects which were part of an early action plan were incorporated on an individual project basis. Late action projects were aggregated by subarea for incorporation into the model. A second unique feature of the model was the incorporation of an environmental alternative. This involved the economic evaluation of transferring the corner use of center pivot irrigated fields from agricultural production

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1/ This paper was developed prior to the organizational change in which the Economic Research Service was renamed the Economics, Statistics and Cooperatives Service.

to wildlife habitat. Without additional flood control and irrigation project action beyond that already funded, the average annual public cost (referred to as "adverse effect" in the study report) of transferring the corner areas to wildlife habitat was estimated through the analytical system at about 180 thousand dollars annually or about \$14.00 per corner acre.

The model was developed to establish base year and projected agricultural acreage and production, provide data for multiple objective (MOP) accounts and OBERS analyses, measure impacts of alternative actions, check physical accounting of resource use and make other analyses such as those concerning drought effects.

An Overview of the Procedures
For the Colorado Rio Grande Type IV Study
ESCS - SCS Linear Programming Model

by

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and
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INTRODUCTION

As part of the Colorado Rio Grande Type IV River Basin Study, the Economics, Statistics, and Cooperatives Service and the Soil Conservation Service jointly developed a linear programming (LP) model for the use in making River Basin analysis on non-federal crop, pasture and rangeland in the San Luis Valley of Colorado.

PURPOSE

There were six purposes for developing the ESCS-SCS LP model in the Rio Grande Study:

1. To establish a base year (1970-1972) and projected crop, pasture and range bases for the years 2000 and 2020.
2. To provide input to the River Basin Type IV Study MOP and other accounts and to provide data for the OBERS analysis.
3. Measure impacts of alternative land and water programs.
4. Measure impacts of other alternative actions including impacts of placing center pivot irrigation corners into wildlife habitat.
5. To check the physical accounting of resource needs and utilization.
6. Make certain other potential evaluations such as the economic effect of drought situations on the study area.

Study Area Description

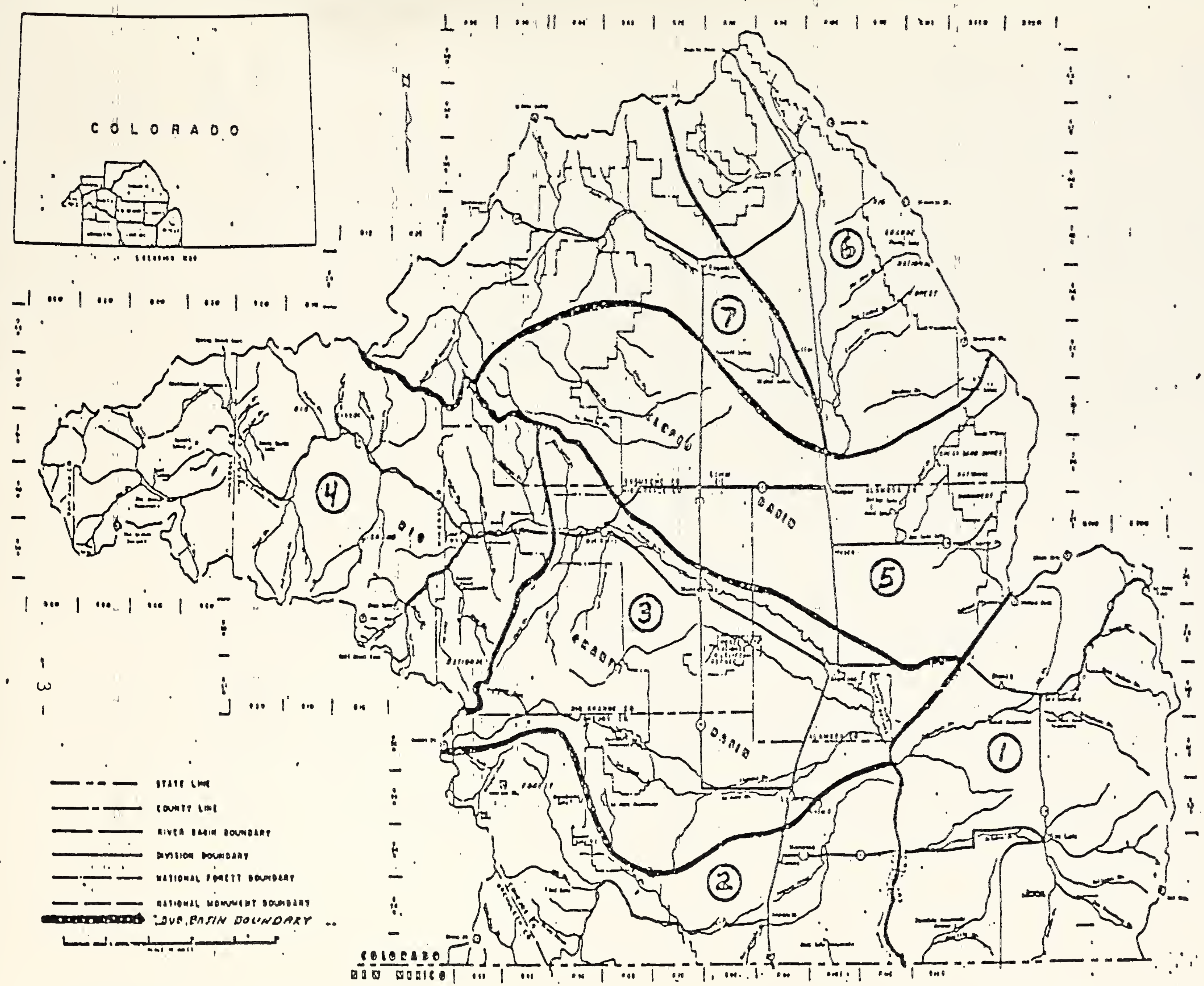
The study area is located in South Central Colorado and is bounded by the Sangre de Cristo Mountain Range on the east, the Rocky Mountains and the Continental Divide on the west and the state of New Mexico on the south. It is comprised of all or nearly all of Alamosa, Rio Grande, and Costilla counties and portions of Conejos, Archuleta, Mineral, Hinsdale, San Juan and Saguache counties. Elevations range from about 7,500 feet in the valley floor to over 14,000 feet on the mountain peaks. The valley floor is relatively flat and is characterized by a low rise which divides the Rio Grande drainage area from the Closed Basin. Winters are extremely cold, and the growing season is short. For study purposes, the area was divided into seven subareas, but subareas 3 and 4 were combined for the ESCS-SCS LP model. See map, figure 1.

General Approach

The analytical system used in the study was a profit maximizing linear programming model. It consisted of a profit maximizing objective function and a series of simultaneous equations used as resource constraints and for accounting purposes. The primary constraints were on land and water along with upper and lower limits on crop production and acreage.

The first run was used to establish a base representing an average of the years 1970-72. That is, the model was designed to closely approximate the agricultural land use between 1970-72, but for the sake of consistency, 1974-75 prices and costs were used for all runs--base and projected.

Following the base year run, a total of four runs were made to represent the projected years 2000 and 2020 under the assumption that none of the



RIO GRANDE BASIN

COLORADO

projects and programs within the plans under study (except for those already funded) would be carried out. Two of these runs were made to evaluate the cost of transferring the corners of center pivot irrigated fields to wildlife habitat for each projection year.

Three plans were evaluated in the Rio Grande study, i.e. National Economic Development (NED), Environmental Quality (EQ) and an Alternative Plan (ALT). The latter two called for the transference of the corners of center pivot irrigated fields to wildlife habitat. The costs associated with the foregone corner production were considered in two parts:

1. A loss attributed to corner areas which would exist without the EQ or ALT plan -- this was accounted as a loss due to land conversion.
2. A cost due to reduced output on corner areas that come in as a result of the EQ or ALT plan. This was accounted as a reduction in irrigation benefits.

The without corner irrigation versus the with corner irrigation runs were primarily managed through the land requirements. Where corner irrigation was included, an acre of land was required for each acre of irrigated production while 1.2 acres of land were required for each acre of production where the corners were transfered to wildlife habitat.

The agricultural (excludes forestry measures) portion of the plan called for nine early action flood control, sediment control and irrigation projects for construction prior to year 2000. These projects were added to the year 2000 without project run as activities based upon crop, soil association, irrigation type (surface or center pivot) and subarea. A total of thirty-four additional irrigation projects were added

for the 2020 long run NED plan. Constraints were placed such that these projects were forced into solutions at levels determined through Watershed Investigation Reports (WIRs), Preliminary Investigations (PIs) and map inspection.

The EQ plan called for only two early action projects which were heavily oriented toward sediment, mine tailing and flood control. In addition, the plan called for placing all center pivot irrigation corners into wildlife habitat cover.

The alternate plan called for the entire set of projects included in the NED plan plus the transfer of all center pivot corner into wildlife habitat.

Twelve projected runs were developed in total:[1/]

1. Two runs, year 2000 for without additional project action -- one assuming crop production in the center pivot field corners and one assuming wildlife habitat in the center pivot field corners. The difference in the objective values (following adjustments)[1/] represented the loss due to land conversion.

2. Two runs for year <u>2020</u> without additional project action under the same conditions and assumptions as in #1.

1/ Several adjustments were necessary in the objective function net returns and differences in net returns. First, costs associated with crop buying activities, added only to insure feasible solutions, were not real costs in the programs, therefore, these were deducted from the objective net return values. Secondly, information received subsequent to the LP runs revealed cost and return difference between the corner areas and the center areas of center pivot fields. A cost of establishing and maintaining wildlife cover in the corners was also estimated. As a result, an adjustment factor was calculated to adjust the net return differences between the runs assuming crop production in the corners and the runs assuming wildlife habitat in the corners. The adjustment factor was calculated as follows:

$$\text{Ratio} = .49 = \frac{\text{Forgone net returns in corner per acre + cost habitat cover per acre}}{\text{Net returns in center pivot area per acre}}$$

3. Runs for years 2000 and 2020 NED Plan assuming crop production in the center pivot field corners. These runs were used to calculate the reduction in irrigation benefits due to center pivot field corner transference to wildlife habitat in the alternate plan.

4. Runs for years 2000 and 2020 alternate plan assuming wildlife habitat in the center pivot field corner areas. The adjusted differences[1/] between these runs and #3 runs were utilized in calculating the reduction in irrigation benefits due to corner transference to wildlife habitat in the alternate plan.

5. Years 2000 and 2020 EQ Plan runs assuming wildlife habitat in the center pivot field corner areas.

6. Years 2000 and 2020 EQ Plan runs assuming that crop production would take place in the center pivot corner areas. These runs did not represent any of the plans evaluated, but were used to evaluate irrigation losses from transferring center pivot field corners to wildlife habitat as stipulated in the EQ plan.

Basic Model Structure

The basic analytical tool was a profit maximizing linear programming model composed of a matrix consisting of a series of simultaneous equations. The first equation (known as the objective function) was designed to maximize profits subject to meeting the conditions of the remaining equations. The remaining equations served as constraints in the form of equalities, maximums or minimums relative to certain prescribed right hand side values.

Column Activities (See Figure 2)

The vertical columns in the matrix consisted of column activities, slack activities designed to permit inequalities and the right hand sides of the row equations. Column activities represented crop, pasture and range production,

FIGURE 2

Schematic Diagram - Rio Grande Colorado
ESCS-SCS - LP Matrix

ROWS	COLUMNS				
	PRODUCTION	TRANSFER	BUY		RIGHT HAND SIDE
Objective	(Net Returns and Costs)			=	Maximum
Land Requirements	+1			<	Irrigated or non-
	+1			<	irrigated soil
	+1			<	association subarea
	+1			<	acreages
	+1			<	
Water Transfer	Coefficient = field requirement	Transfer water to irrigated crop and pasture. See Figure 3.		≤	0
				≤	0
				≤	0
				≤	0
				≤	0
Water Transfer		Pick up from water supply. See Figure 3.		≤	Ground and surface
				≤	water available
				≤	by month
				≤	
				≤	
Production	+yield		+1	≥	Production
	+yield		+1	≥	Requirements
	+yield		+1	≥	
	+yield		+1	≥	
	etc.		etc.	≥	

Bounds	Production Minimums and/or Maximums		Buy Maximums

FIGURE 3

COLORADO RIO GRANDE ESCS-SCS LP - SUBAREAS 3 AND 4 - WATER TRANSFER

By Growing Season, Months and Water Source

Rows	Surface						Ground					Pump 3[1/]					
	AprS3	MayS3	JunS3	JulS3	AugS3	SepS3	MayP3	JunP3	JulP3	AugP3	SepP3	MayP33	JunP33	JulP33	AugP33	SepP33	RHS[2/]
WAPRS3	-1									Transfer water to irrigated crop and pasture							≤0
WMAYSP3		-1					-1										≤0
WJUNSP3			-1					-1									≤0
WJULSP3				-1					-1								≤0
WAUGSP3					-1					-1							≤0
WSEPSP3						-1					-1						≤0
WMAYP3												-1					≤0
WJUNP3													-1				≤0
WJULP3														-1			≤0
WAUGP3															-1		≤0
WSEPP3																-1	≤0
WRAPRS3	1									Obtain from water supply							≤ A
WRMAYS3		1															≤ V
WRJUNS3			1														≤ A
WRJULS3				1													≤ I
WRAUGS3					1												≤ L
WRSEPS3						1											≤ A
WRMAYP3							1					1					≤ B W
WRJUNP3								1					1				≤ L A
WRJULP3									1					1			≤ E T
WRAUGP3										1					1		≤ E
WRSEPP3											1					1	≤ R

1/ Pump 3 transfer activities pick up ground water only and transfer it to center pivot irrigation.

2/ Right hand sides of the equations.

water transfer from supply to use, and crop purchase activities designed to assure solution feasibility. The column activities were divided into six subarea groups (five subareas plus 3 and 4 combined). See map, figure 1, page 3.

The first set of the column activities representing crop, pasture and range production contained activities for the production of winter wheat, spring wheat, oats, feed barley, malting barley, alfalfa hay, small grain hay, grass hay, potatoes, vegetables, minor crops, cropland pasture, idle cropland, crop failure, non-cropland pasture, range adequately treated and range needing treatment. These crop, pasture and range activities were entered separately for each suitable soil association (capable of sustained production by subarea). In addition, each irrigated crop in each of the subarea and soil association groups was further divided into from one to three irrigation groups as depicted in figure 3, page 8:

1. Surface irrigation with a full water supply.
2. Surface irrigation with a short late season water supply.
3. Center pivot sprinkler system with a groundwater source.

The next set of activities for each subarea group consisted of the monthly water transfer activities. For each subarea group there were water transfer activities for surface water April through September, pump water May through September and pump water for center pivot sprinkler only May through September. These activities were designed to obtain water from the supply sources by month and transfer the required water to the irrigated crop and pasture activities. The water transfer activities operated within subareas and with heavy constraints on crop, soil association acreages and project acres; these transfers operated within the confines of water rights. Figure 2 depicts the layout for these activities for the combined subareas 3 and 4.

In figure 3, surface and groundwater were obtained through the bottom rows starting with the row labelled WRAPRS3 to row WRSEPP3. The first six rows picked up water from surface water supplies. The maximum water supplies (availabilities) in acre feet were placed into the right hand side of these rows (equations). These right hand sides were reduced from the actual water availability in acre feet to account for delivery losses to the fields as estimated by the SCS hydrologist.

The first twelve rows in figure 2 were designed to pick up the water from the lower rows and provide the water to the various irrigated crop and pasture activities which required irrigation water. The first six rows delivered water to surface irrigation (either full or short supply). This water could be supplied through either pump or surface sources. The next five rows delivered water to the pivot irrigation crop activities on the various soil associations within subarea group 3 and 4.

Returning to the columns (activities) in figure 3, the first six (left to right) were designed to pick up surface water for delivery to surface irrigation. The next five were designed to obtain pump water for surface irrigation use and the last five were designed to obtain pump water for center pivot irrigation only.

The final set of column activities was designed to buy units (by cwt, AUMs, etc, as depicted in figure 2) of the various crop, pasture and range activities in the event that monthly irrigation water or irrigable land availability could not meet the production requirements in the production rows. There was one activity for each crop, pasture and range type for the entire study area. These activities were buy oats, spring wheat, feed barley, malting barley, alfalfa hay, small grain hay, grass hay, potatoes and grazing in AUMs.

Slack activities carried +1 or -1 coefficients allowing the sum of the remaining term values to be equal or greater or conversely greater or less than the right sides. The right hand side values in the right hand side column will be described in the row composition section next.

Row Composition

The rows constituted a series of linear equations or functions. Non-zero terms for the equations were located under the appropriate column activities. The first row constituted the objective function which was the key function for solving the program. This function maximized the returns to land and management for the study area subject to satisfying the values of the remaining equations (feasibility). The left hand side of this equation consisted of a set of additive terms representing the net returns from the various crop, pasture and range activities and costs from the water supply and crop buying activities. The summation of the solution levels of these positive and negative term values, as determined by the linear program, equalled the maximum possible net returns to the study area subject to the conditions of the remaining functions.

Per acre crop net return or loss values (return or loss to land and management) were computed by subtracting per acre costs from per acre gross returns. Per acre crop yields and Water Resource Council (WRC) prices were used to calculate per acre gross returns. There were two crops for which WRC prices were not available. The first was the malting barley price which was based upon Coors Brewery estimates; the second was the pasture price, which was based upon SCS local estimates. Base crop yields by soil association were estimated through an inventory program known as Colorado SRG8, developed by ESCS with assistance from local and state SCS personnel. The inventory data were adjusted to conform with

Colorado Crop Reporting Service and Statistical Reporting Service estimates of crop acreage, yield and production.

Basic crop costs, including water costs, were developed by Colorado SCS state staff personnel and represented year 1974 -- the same as prices. Harvest costs were placed on a per unit basis (bushel, ton, etc.) and then charged on the basis of per acre yields.

The land constraint functions followed the objective function. The left hand side term coefficients represented one acre of land for each acre of crop, pasture or range activity which entered the solution. The right hand sides of these equations represented the maximum amount of each soil association available for use.

The next set of rows (equations or functions) represented monthly water use by crops and operated as transfers through the water supply activities. Figure 3 illustrates the operation of these rows. The first six rows transferred surface or groundwater to the various crop activities for use as surface irrigation. The next five rows transferred groundwater only for pump water use in center pivot irrigation systems. The crop activities carried coefficients representing the irrigation water field delivery requirements. The zero right hand side values forced the crop activities to draw water from the water supply.

The next set of rows, also depicted in figure 3, represented the water pickup from surface and groundwater supplies to the surface and groundwater transfer activities. The right hand sides represented available field delivery at the farm head gates.

The following set of rows represented production requirements and consisted of one set of rows for all of the subareas combined. The activity coefficients consisted of per acre crop and grazing yields. A positive one coefficient was placed under the appropriate purchase activities such that the solution could permit purchasing if the OBERS[1/] demand could not be met. The

right hand sides then represented a minimum OBERS requirement. Inasmuch as potatoes and malting barley were the two most profitable crops in the study area during the study period, maximum production limits were placed on these crops to prevent over-replacement of less profitable crops. This entailed OBERS projections for potatoes and Coors Brewing Company projections for malting barley. This appeared reasonable since these crops are primarily grown under contract. One production row (function or equation) was included for each of the following; oats, spring wheat, winter wheat, feed barley, malting barley, alfalfa hay, small grain hay, grass hay, potatoes, grazing (pasture) in AUMs, vegetables, idle cropland, crop failure and minor crops.

Activity Bounds

In order to closely simulate base year crop, pasture and range land use patterns, each of the crop, pasture and range activities (by soil association, subarea, and irrigation type) was given an upper limit in acreage which closely approximated the 1970-72 acreage. This was obtained through the Colorado crop acreage yield production inventory (SRG8). Because the Rio Grande Type IV land use work group felt that land use would not drastically shift in future years, the same acreage limits were used for the projected years with several exceptions to be noted in the next section. Crop production was allowed to increase in the projected runs through projected yield increases.

Future Without Program Adjustments

The major kinds of adjustments were made in the projected without-program runs. First, there were changes in several of the activity bounds, noted in the last section. These were upward changes in malting barley acreage and center pivot irrigation acreage for the production of several crops where upward trends were noted in recent years. The projected upper limits on these

1/ Office of Business Economics and Economic Research Service projections allocated to the study area Regional shore.

acreages were based on extrapolations arbitrarily dampened from linear extensions.

The other kind of adjustments pertained to crop yield projections. These were developed by multiplying 1970-72 yields by 1980, 2000 and 2020 projected year indices. The indices were developed by NRED personnel in Berkeley, California, utilizing the Spillman function and concurred with by the river basin planning participants. The Spillman function is concave downward (increases at a decreasing rate) and over time approaches but never reaches some prescribed maximum. The 2020 linear extrapolated values were used for the maximums in this study.

Future With Program Adjustments

The main feature of the with program runs was the inclusion of watershed project activities. Nine early action projects were incorporated into the 2000 NED and alternate models (the latter which also assumed the placement of all center pivot field corner areas into wildlife habitat). Two of the nine projects which dealt with flood and sediment control were incorporated into the 2000 and 2020 EQ plan models and additionally thirty-four long-range projects were incorporated into the 2020 NED and alternate models.

Project effects were derived primarily from Watershed Investigation Reports (WIRs) supplemented by study area soil association maps. Project area delineations were sketched on soil association maps and the soil association distribution by acreage was estimated. Crops were assigned on the basis of WIRs cropping distribution by soil association derived from the SRG8 crop acreage, yield and production inventory for years 1970-72.

Water efficiency gains derived from the project action were calculated and the additional water was added to the monthly water supply right hand sides by subarea.

Upper and lower activity bounds were established so as to very closely establish or lock in the actual soil association acreages, cropping patterns and water use. In addition, all project net benefits were distributed to the projects such that the objective values of the solutions would reflect net profit and losses from the various production activities plus the total net project benefits incorporated into the various models.

The matrix size of the models varied by run with a maximum size of 238 rows x 879 columns including slack vectors. The runs were made on a CDC 7600 computer at the Lawrence Berkeley Laboratory in Berkeley, California at a cost of about $4.00 to $8.00 per run.

SOLUTIONS

It must be emphasized that the costs and returns used for the report and the Rio Grande were based on year 1974. Subsequent year updating indicates some shifting in the economic relationships, especially in the economics of production in the center pivot corner areas. These updated relationships are discussed in the ESCS staff paper, "Economic Analysis of Utilizing Corner Areas of Center Pivot Irrigated Fields for Wildlife Habitat in the San Luis Valley, Colorado" by Ronald R. Rhoade, March 1979.

The net return or beneficial effect of each solution was determined by subtracting the net value of the buying activities from the solution objective function values. Table 1 lists objective function solution values adjusted for the purchase (buy) activities. The net return values are overstated because they do not allow for the cost of establishing wildlife cover in corners and also do not account for reducted yields and higher costs in the corner areas. These adjustments are accounted for in the last column of table 1, entitled Adjusted Difference In Net Return. The values in the last column

of table 1 were used to establish points on a graph representing the economic loss due to the transference of the center pivot field corners to wildlife habitat. A gradual buildup in corner transference was assumed between year 1978 and year 2000. Following year 2020, the trend in the adverse effect (loss or cost) was carried to year 2078 by extending the 2000 to 2020 trend. The streams of adverse effects were then discounted to 1978 and amortized for 100 years at 6 7/8% interest. Following amortization, the discounted-amortized effect, using adjusted differences between runs 1 and 2 along with runs 3 and 4, was calculated at $180,000 annually, as a loss due to land conversion. With the addition of the two EQ projects, the adverse effect increased to about $184,000. The approximately $4,000 difference was reflected as an irrigation benefit reduction because it was in addition to the without project situation. For the alternate plan, the total adverse effect was calculated at about $204,000 for a difference of about $24,000 from the without situation, this number also reflecting an irrigation benefit reduction in the alternate plan.

TABLE 1

Costs (Adverse Effects) Associated with Center Pivot Irrigation,
San Luis Valley, Colorado - 1974

Run	Year	Land requirement per acre of crop	Plan evaluated	Utilization	LP net return ($1000)	Diff. in net return ($1000)	Adjusted diff. in net return ($1000)
1	2000	1.2	Without	To obtain loss to land conversion W/O plan - 2000 and 2020	36,210	709	348
2	2000	1.0	"		36,919		
3	2020	1.2	"		38,234	568	278
4	2020	1.0	"		38,802		
5	2000	1.2	EQ	To obtain loss to land conversion W/O plan and irrigation benefit reduction - EQ plan 2000 and 2020	35,920	724	355
6	2000	1.0	"		36,644		
7	2020	1.2	"		38,253	584	286
8	2020	1.0	"		38,837		
9	2000	1.2	ALT	To obtain loss to land conversion W/O plan and irrigation benefit reduction ALT plan 2000 and 2020	39,637	539	264
10	2000	1.0	NED		40,176		
11	2020	1.2	ALT		44,062	1,499	735
12	2020	1.0	NED		45,561		